Available Online at http://www.journalajst.com

ISSN: 0976-3376

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 11, Issue, 03, pp.10840-10844, March, 2020

RESEARCH ARTICLE

EFFECT OF TEMPERATURES ON THE DRYING KINETICS OF HOT PEPPER

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ARTICLE INFO

Article History:
Received 15th December, 2019
Received in revised form
29th January, 2020
Accepted 17th February, 2020
Published online 28th March, 2020

Key words:
Hot Pepper, Drying, Moisture Diffusivity, Activation Energy.

ABSTRACT

Effect of temperatures on the drying kinetics of hot pepper drying was done using hot air oven4 lots for dying at 80,85,90 and 95^{O}C respectively to moisture content of 10 g moisture/100g dry solid, Changes in moisture content with drying time were evaluated to obtain drying curves. Drying rate curves was plotted using residual moisture/ time against the moisture contents to obtain critical moisture content (M_c) and equilibrium moisture content (M_e), moisture ratio against drying time. Fick's unsteady state plot was employed to obtain moisture diffusivity (D_{eff}), and a plot of ln D_{eff} against 1/T was used to obtain frequency factor (D_o) and activation energy (E_a).The M_c 2, 3.6, 3.8, 3.8g H_2O/ g dry solids; M_e0.08, 0.08,0.12, 0.16g H_2O/ g dry solids D_{eff}1.95x10^{-08}, 2.40x10^{-08}, 2.43x10^{-08}and 2.45x10^{-08}m^2/s for drying temperature (80,85,90 and 95^{O}C), D_o3.00x10^{-08}m^2/s and E_a16.53kJ/mol. Drying temperatures affects drying times the minimum energy required for drying hot pepper is 16.53kJ/mol.

Citation: ***Adamu, H. D., Ariahu, C. C. and Igbabul, B.D.*** **2020.** "Effect of temperatures on the drying kinetics of hot pepper", *Asian Journal of Science and Technology*, 09, (08), xxxxxxxxxx.

INTRODUCTION

Pepper also are referred to as chillies, chile, hot peppers, bell peppers, red peppers, pod peppers, cayenne peppers, pimento, scotch bonnet and capsicum in different parts of the world. (Karpate, 2010). In Nigeria, hot pepper is referred to as ''atarhu'' in Hausa, ''atarodo'' in Yoruba. it is used as spices in preparing soups, sauces, spicy dishes or are used as medicines, cosmetics and plant insecticides (Take *et al*., 2012; Dognoko, 2013). Fruit and vegetable production is limited in Nigeria to certain seasons and localities because they deteriorate a few days after harvest because of their high moisture content. Studies have shown that about 30% of fruits and vegetables produced are lost on the way from producers to consumers (Tunde- Akintunde and Akintunde 1996; Peter 2010). Drying involves heat and mass transfer that result in irreversible changes (either physical or as a result of chemical or biochemical reactions) in the product. Drying can be carried out either by traditional or industrial drying. Industrial drying consists of sun, solar, hot air and other drying methods. Drying temperatures and time affects the overall quality of pepper, resulting to poor quality and unsalable products. (Soysal *et al*., 2009).

Hot air drying has been till date the method of drying industrial scale of pepper in Nigeria and other part of the world (Tunde-Akintunde *et al*., 2005). The determination of the drying characteristics as a function of drying conditions could help in predicting suitable drying conditions (Hamdami*et al.,* 2006). The moisture removal of a crop and its dependence on the process variables is indicated by its drying kinetics which is essential for the development of reliable process models (Guine and Fernandes, 2006). The aim of this research was to investigate the effect of temperatures on the drying kinetics of hot pepper.

MATERIALS AND METHODS

Drying: 200 g of fresh each pepper was dried using hot air oven with periodic weighing in order to obtain data for subsequent analysis and to ensure effective drying as described by Tunde-Akintunde and Afolabi(2008); Darvishi*et al (*2013); Yilmaz *et al*.(2016).

Drying rate;

The drying rate of samples was calculated by;

$$\frac{\Delta M}{\Delta t}\ (DR)=\frac{Mt+\Delta t-Mt}{\Delta t} \qquad (1)$$

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where;

$M_{t+\Delta t}$= moisture content at t + Δt (g moisture/g dry solid)
Δt= change in time (hour)
M_t= moisture (g moisture/g dry solid)
DR= drying rate (g moisture/g dry solid hr)
Experimentally DR is deduced by taking the slope of tangent of moisture-time graph

Moisture diffusivity: Fick's second equation of diffusion was used to calculate the effective diffusivity, considering a constant moisture diffusivity, infinite slab geometry and uniform initial moisture distribution:

$$D_{eff} = D_o \exp\left(\frac{-Ea}{RT}\right) \quad (2)$$

where;

D_{eff} : effective moisture diffusivity (m^2/s)
L:is the thickness (here half) of layer (m).
M: is moisture content at any time (g H_2O/ g dry solid),
M_o: is initial moisture content (g H_2O/ g dry solid),
M_e = equilibrium moisture content (g H_2O/ g dry solid) and
t = time in hours.

Plotting of lnMR versus time serves calculation of the effective moisture diffusivity and a straight line can be obtained with a slope of (S) as expressed below:

$$S = \pi^2 Deff / L^2 \quad (3)$$

Where: L = ½ of thickness of the sample

L= 80°C 9.7, 85°C 9.5, 90°C 9.25 and 95°C 8.67 cm

Activation energy: The E_a for diffusion was determined from the slope of Arrhenius-type equation plotting a graph of ln D_{eff}vs 1/T serves as the calculation of the activation energy with slope S as expressed below;

$$\ln D_{eff} = \ln D_o \exp\left(\frac{-Ea}{RT}\right) \quad (4)$$

(Arrhenius equation)

Where;

$$S = \frac{-Ea}{RT} \quad (5)$$

S; slope of the graph
D_0: frequency factor (m^2/s)
D_{eff}: effective moisture diffusivity (m^2/s)
E_a: activation energy (kJ/mol)
R: universal gas constant (kJ mol^{-1} K^{-1})
T: temperature (K^{-1})

RESULTS AND DISCUSSION

Drying kinetics: The moisture content of hot pepper was brought to 10% moisture which is a standard moisture content of dried spices (ISO 2000).

Drying curves: The relationship between Hot pepper residual moisture content with drying time for drying temperatures 80, 85, 90, 95°C. A nonlinear decrease in the residual moisture content with increase in drying time was observed, moisture loss was fastidious initially for 80°C it reduced from 6.94g/g solids to 1.33g/g solid within 2 hours. After 2 hours of the drying time drying was slowed these also the same for during temperatures 85,90,95°C the drying was slowed after 1hour 30 minutes. The curves obtained are in-line with drying curves for food materials as observed by researchers (kaymak-Ertekin, 2002 for green pepper and red pepper; Tunde-Akintunde and Afolabi, 2010 for chilli pepper; Darvishi *et al*., 2014 pepper.). As drying temperature increases the drying time decreases. According to the kinetic theory, this reduction in drying time is due to the effect of increased state of energy of the water molecules as the temperature increased. Higher state of energy allows the water molecules to escape easier and faster from the product. A number of investigators (Prabhanjan *et al.* 1995; Maskan *et al.* 2002) observed that higher temperatures resulted in higher differences between the saturated water and the partial pressure of water vapour in air at a given temperature. This larger water vapour pressure deferential is one of the driving forces of the outward moisture diffusion process. Maskan *et al.* 2002.

Drying Rate Curves: The effect of drying temperatures on the rate of moisture loss for the hot pepper samples are presented in the drying rate curves shown in figure 2. The drying rate curves with moisture content for temperatures 80, 85, 90, 95°C. as hot pepper drying temperature increases the constant rate period of drying becomes less significant. Drying of hot pepper was observed in the falling rate period this is governed by moisture diffusion in the solid. similar with the findings of chili pepper (Tunde-Akintunde and Afolabi, 2008, pepper Darvishi *et al*., 2013: kiwifruit (Femenia *et al.,* 2009). And with other fruits and vegetables, Mass transfer of moisture in this period is by diffusion. The rate of drying falls continuously with time because moisture migration to the surface is hindered by resistance to internal transport (Baker, 1997). As hot pepper drying rate increases the moisture escape increases. similarly observed by Peter *et al.,* 2010 in tomatoes. Initially the moisture content of hot pepper is high at the initial drying phase which increases the absorption power of the dryer and higher drying rate was observed as drying progresses the drying rate decreases the absorption power which results in the fall in drying rate.

As drying temperature increases the drying rate increases too as reported by Darvishi *et al*., 2013; Wang *et al*., 2007; Soysal *et al*., 2006; Therdthai and Zhou, 2009. Critical moisture content from table 1 of the dried pepper varies with drying temperatures. It decreases with increase in drying temperature (2.18, 1.96, 1.95, 1.93 (g H_2O/g dry solids) for 80, 85, 90, 95°C, respectively. although the values are within the range of moisture content of vegetable ranging below 5.0g/g dry solids (Srikiatden and Roberts, 2007). The onset of the falling rate drying period as observed the drying occurs in the second falling rate period were increase in temperature and the drying of hot pepper increases too this also was observed by (Yilmaz, 2017,in pestil, Tunde-Akintunde and Afolabi, 2010 , in chilli pepper, Darvishi *et al*., 2013 in hot pepper): indicates that diffusion of water processes from the inner wet regions through the dry outer layers for pepper is also activated by high temperature and becomes higher as drying temperature increases, thus increasing the rate at which agricultural products are dried Tunde-Akintunde *et al*. 2005.

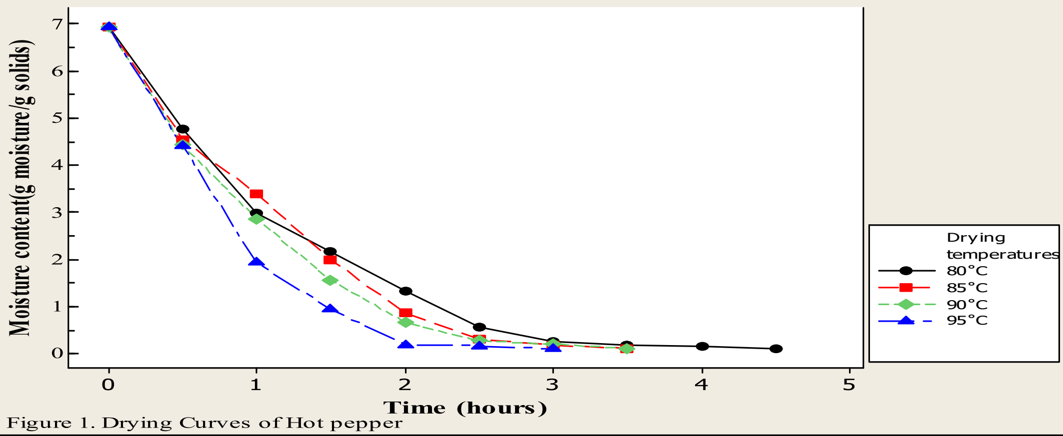

Figure 1. Drying Curves of Hot pepper

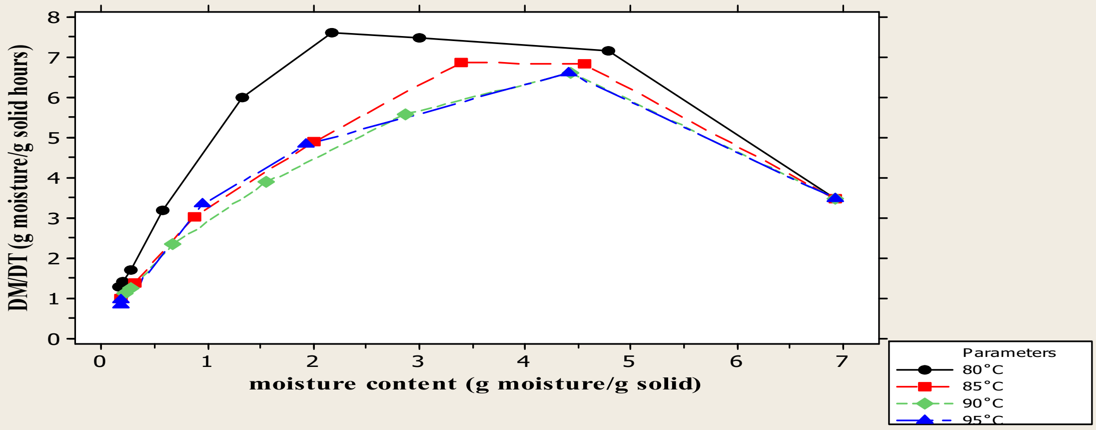

Figure 2. Drying Rate Curves for Hot Pepper

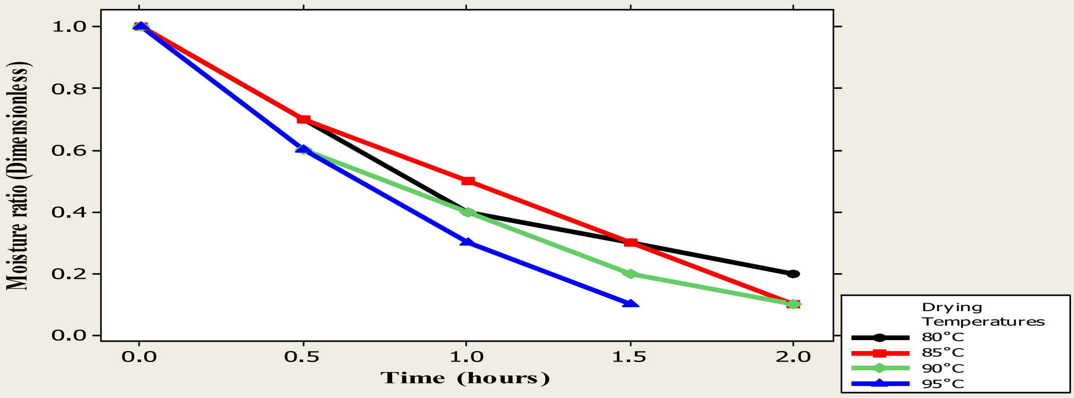

Figure 3: Fick's Unsteady state Moisture Ratio Vs Time plots

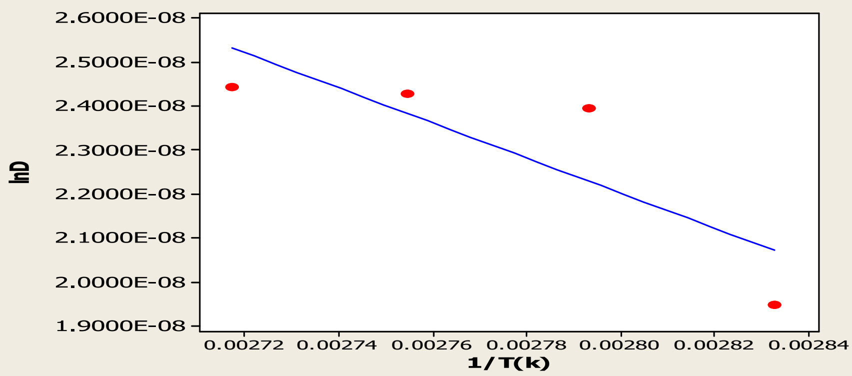

Figure 4. Temperature Dependancy of Moisture Diffusivity in Hot Pepper Drying

Table 1. Drying Rate and Fick's Unsteady State Derivatives for Dried Hot Pepper.

Parameters		Drying temperature (^{O}C)			
		80	85	90	95
N		5	5	5	4
r^2		0.95	0.98	0.98	1.0
M_c (g H_2O/ g dry solids)		2	3.6	3.8	3.8
M_e(g H_2O/ g dry solids)		0.08	0.08	0.12	0.16
$D_{eff} m^2/s$		$1.95x10^{-08}$	$2.40x10^{-08}$	$2.43x10^{-08}$	$2.45x10^{-08}$
$D_o(m^2/s)$	$3.00x10^{-08}$				
E_a (kJ/mol)	16.53				

D_{eff} - = Effective moisture diffusivity (m^2/s) D_o = frequency factor (m^2/s)
E_a = Activation energy (kJ/mol) M_e =Critical moisture (g H_2O/ g dry solid)
M_c = Equilibrium moisture (g H_2O/ g dry solids) n= number of points
r^2 = Regression coefficient

Moisture Ratio Curve: The effect of drying temperatures on the moisture ratio loss for the hot pepper samples are presented in the moisture ratio curves shown in figure 3.

Moisture Diffusivity: The use of Fick's second law it was observed that drying temperature has influence on the moisture diffusivity therefore drying at higher temperature 95°c gave the highest value for D_{eff}2.45x $10^{-08}$$_f$$m^2/s$ from table 1. Darvishi *et al*., 2013 reported that the effective moisture diffusivity for hot pepper ranges from 2.36 $x10^{-7}$ to $8.35x10^{-8}$- 10^{-9}). The values of D_{eff} are comparable with the reported values of 5.10–8.32 x· 10^{-10} m^2/s mentioned for red pepper by Di Scala and Crapist, 2008, 3.72– $9.96x10^{-10}$ m^2/s for *Jaranda* variety red pepper as reported by Sanjua´n *et al*., 2003; 0.360–2.01 $x10^{-10}$ m^2/s for green peppers as reported by Ertekin, 2002; 0.705 and 2.618 $x10^{-9}$ m^2/s for green bell pepper by Doymaz and Ismail, 2010; 2.25–2.74x 10^{-8} m^2/s for red pepper Doymaz and Pala, 2002 and 0.31and $87.39x10^{-9}$ m^2/s for red bell pepper (Arslan and Ozcan, 2010, 2011). Variation of moisture diffusivity is dependant with drying temperature as temperature increases the diffusivity increases. Subsequently the diffusivity increases at any level of moisture content the higher the temperatures the higher the diffusivity which results in shorter drying time diffusivity of the results falls within the range of drying of biological materials as also observed the differences between the results can be explained by effect of type, composition, thickness and tissue characteristics of the peppers, method of drying, temperature used and the proposed model used for calculation (Wang *et al.* 2007; Kumar *et al*., 2011).

Temperature Dependency of Moisture Diffusivity in Hot Pepper: The activation energy for the process 16.53kJ/mol. and the D_o $3.00E^{-8}$from table 1 compared with the findings of Darvinshi *et al.,* 2014 and D_o values of 3.996. 10^{-7} m^2/s and 14.194 W/gactivation energy for agricultural products ranges from 12.7-110KJ/mol (Aghbashlo 2008). The differences between the results can be explained by effect of type, composition, thickness and tissue characteristics of the peppers and the proposed model used for calculation. The effect of drying temperatures on the moisture diffusivity for the hot pepper samples are presented in Temperature Dependency of Moisture Diffusivity in Hot Pepper Drying in figure 4 from the results it can be observed that as the drying temperature increase the dependency increases

Conclusion

Drying temperature influences the drying rate, drying time and effective moisture diffusivity of hot pepper. Increased drying temperature resulted in decrease in drying time also. It increases the moisture diffusivity, the minimum energy needed for hot pepper drying Is 16.53kJ/mol.

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